Optimized Integrated Vehicle, Operations, and Network Constellation Design (OptCon)

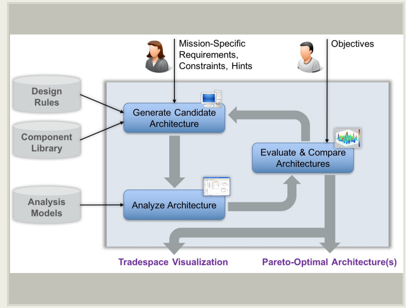
Completed Technology Project (2015 - 2018)

Project Introduction

To date, planetary science investigations have largely been conducted with missions involving a single spacecraft. Looking ahead, NASA scientists are envisioning an era in which distributed sets of sensors are the norm, developing ambitious concepts for fleets of spacecraft with applications to planetary science, heliophysics, and astrophysics. Such fleets, or constellations of spacecraft are considerably more complex to design, particularly due to the highly intricate trade-offs that must be conducted. For instance, the trade between using less, more capable assets, and a larger number of smaller, less capable assets has to be considered. Our proposed innovation aims at developing new technology for assisting engineers in designing such missions and conducting the associated trade-offs. The technology is a critical step towards enabling the design of missions involving multiple spacecraft.

Designing missions involving multiple spacecraft requires consideration of decisions at various levels, including the level of the constellation itself. If the individual assets have only limited capabilities, certain tasks involved in reaching an overall mission objective may need to be distributed among the different spacecraft. For instance, in a hypothetical deep space constellation where large numbers of small spacecraft collect scientific data, and the quantity of this data is large, the capabilities of the collecting spacecraft may not suffice to also pre-process and / or transmit the data back to a ground station. In such cases, additional spacecraft may be required that are, potentially only in part, responsible for pre-processing or communication of the data back to Earth. In addition, fractionation may be used for physical redundancy. Since the number of spacecraft, and their size and performance typically have a strong influence on the cost, probability of mission success, and the scientific benefit, integrated optimization at the level of the constellation, vehicles, and operations must be conducted.

In our concept, we capture knowledge about the general domain of spacecraft missions formally (that is, in a computer-interpretable fashion). This knowledge includes technical constraints, and is captured with reusability in mind in order to rapidly analyze a multitude of mission concepts. Since every mission is unique, additional knowledge is added that is specific to each mission concept. This additional knowledge includes how the overall mission objectives and science goals can be achieved, resource constraints, measures of effectiveness and how mission success can be quantified, risk analysis, and other distinguishing aspects of the mission. Both the mission-agnostic and the mission-specific knowledge is then used to synthesize (that is, generate) a number of candidate mission architectures. These architectures specify the number of spacecraft, their individual size, capabilities and configuration, their primary functions in the constellation, their required interactions, and include an estimation of the overall mission cost and scientific value. The synthesis process is guided by the measures of effectiveness, and any additional technical and resource constraints specified by a designer. This ensures that only the most valuable mission architecture candidates are presented to an



Optimized Integrated Vehicle, Operations, and Network Constellation Design Project.

Table of Contents

end-user and considered for further study.

The developed technology is based on key techniques from Model-based Systems Engineering (MBSE), and borrows concepts from Expert Systems. Specifically, meta-modeling and constraint languages are used for capturing knowledge about the general domain of spacecraft missions, as well as the class of the missions being studied. Concrete mission architectures are generated using sequences of in-place, endogenous model-transformations. The steering of solution candidates towards the most preferred is ensured through the application of metaheuristic optimization algorithms. The overall design problem is captured in a domain-specific language (DSL) designed to support the concepts required to concisely express architecture optimization problems. Integration with a variety of analysis tools allows for sophisticated, non-linear analyses to be performed.

Anticipated Benefits

While the technology is aimed at supporting mission design in early phases, the core concepts can be applied to activities in any phase of the lifecycle. Particularly the application of model transformation rules for the purpose of refining an existing design, or for automated enhancement of partial models to complete a design, can help engineers design systems faster and at even higher quality. Furthermore, errors and missing information can be discovered early, hence helping in ensuring consistency, completeness and coherence. The technology has the potential of significantly enhancing current Model-based Systems Engineering (MBSE) capabilities applied within the context of NASA funded missions - for instance, the planned Europa Clipper mission.

The developed technology can be used to rapidly explore highly complex (i.e., high dimensional) trade spaces. Therefore, the technology enables larger design spaces to be considered during proposal and early phase mission studies. This is particularly useful when designing mission concepts that involve multiple spacecraft. By providing a rule-based mechanism for generating solution candidates from basic, elemental knowledge about a problem domain, the potential exists for emergent solutions to be discovered through computational means. This leads to a natural shift in focus from ideation to analysis, allowing for complex design problems to become more manageable, and more and novel concepts to be considered while preventing premature fixation on a particular design. The reusable nature of the captured knowledge also allows for mission studies quickly and effectively.

Organizational Responsibility

Responsible Mission Directorate:

Mission Support Directorate (MSD)

Lead Center / Facility:

Jet Propulsion Laboratory (JPL)

Responsible Program:

Center Independent Research & Development: JPL IRAD

Project Management

Program Manager:

Fred Y Hadaegh

Project Manager:

Fred Y Hadaegh

Principal Investigator:

Sebastian J Herzig-patel

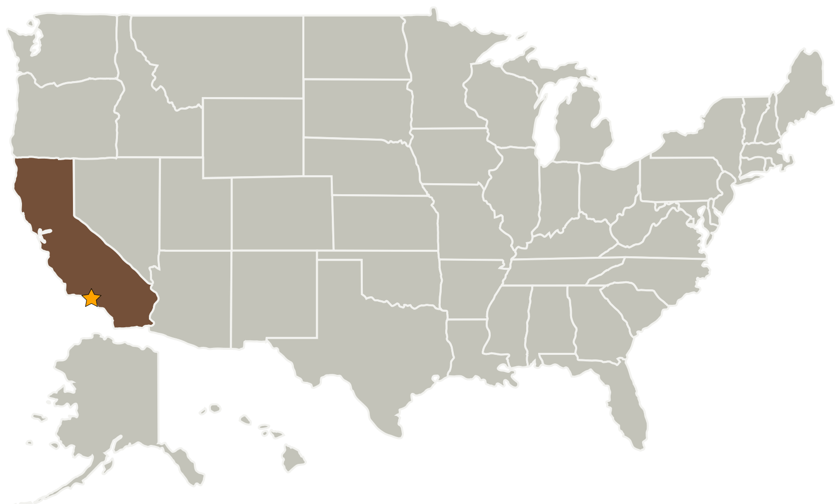
Co-Investigators:

Travis K Imken
Hongman Kim
Sanda Mandutianu

Optimized Integrated Vehicle, Operations, and Network Constellation Design (OptCon)

Completed Technology Project (2015 - 2018)

Primary U.S. Work Locations and Key Partners

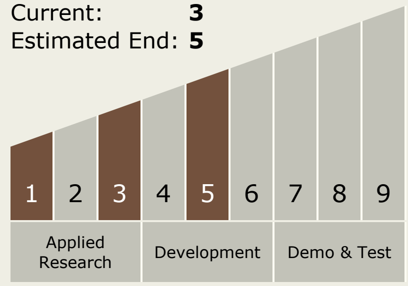


Organizations Performing Work	Role	Type	Location
★Jet Propulsion Laboratory(JPL)	Lead Organization	NASA Center	Pasadena, California

Primary U.S. Work Locations
California

Technology Maturity (TRL)

Start: **1**
Current: **3**
Estimated End: **5**



Technology Areas

Primary:

- TX11 Software, Modeling, Simulation, and Information Processing
  - └ TX11.5 Mission Architecture, Systems Analysis and Concept Development
    - └ TX11.5.2 Tools and Methodologies for Performing Systems Analysis

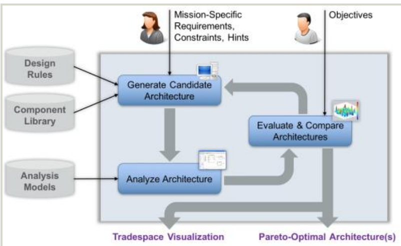
Target Destinations

The Sun, The Moon, Others Inside the Solar System

Supported Mission Type

Planned Mission (Pull)

Images



JPL_IRAD_Activities Project Image

Optimized Integrated Vehicle, Operations, and Network Constellation Design Project.

(https://techport.nasa.gov/image/28007)